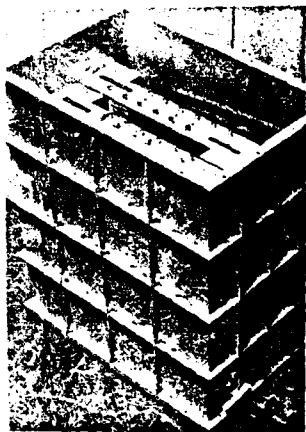TECHNICAL REPORT O-89-1

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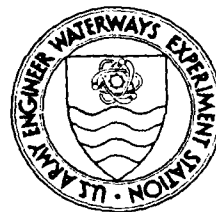
US Army Corps of Engineers

AN EVALUATION OF THE HARDENED DIGITAL RECORDING SYSTEM

by

Robert J. Dinan

Instrumentation Services Division

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi   39181-0631

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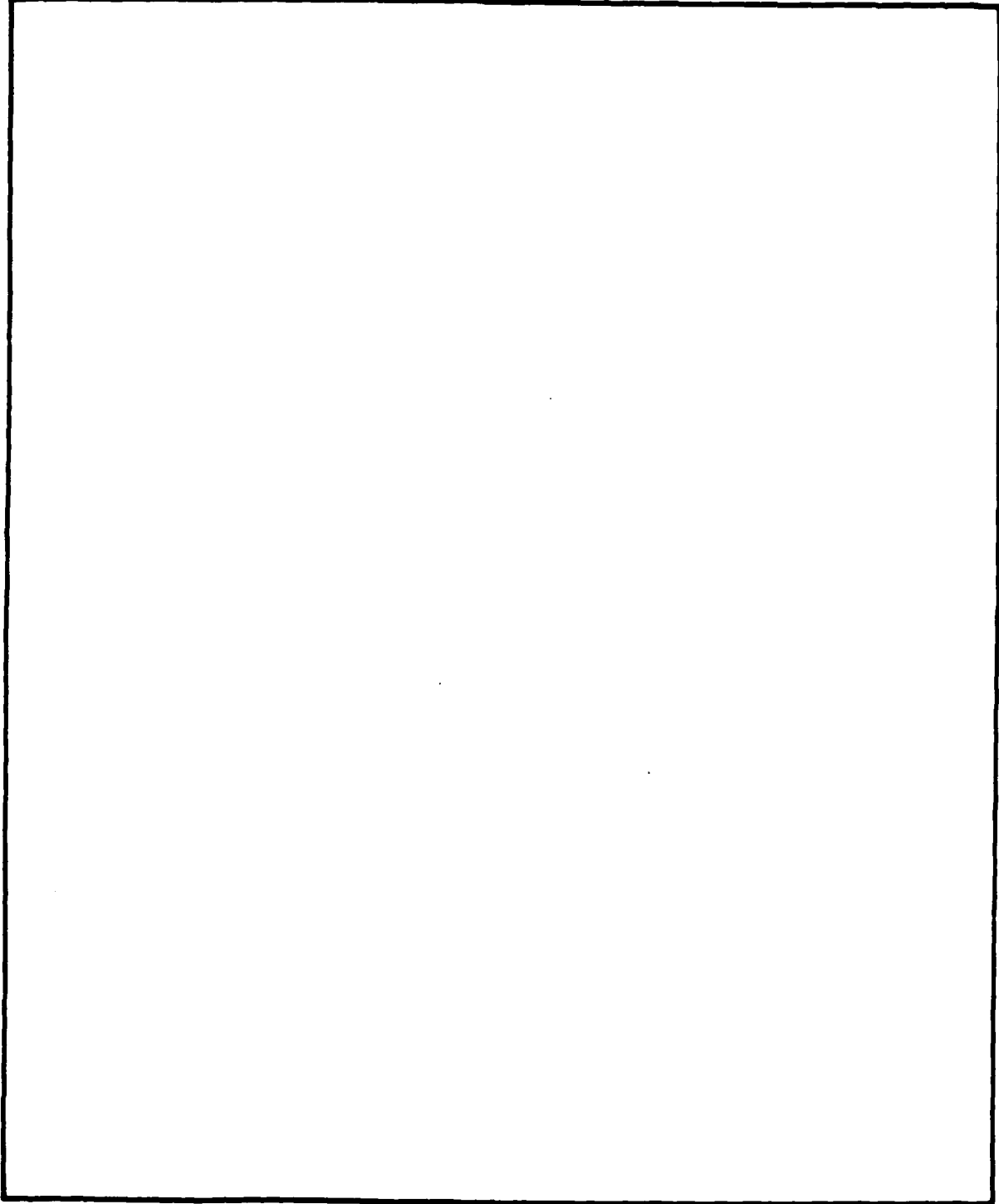## REPORT DOCUMENTATION PAGE

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This report is an evaluation of Kaman Sciences Corporation's Self-Contained, Digital Recording System (SDRS). The SDRS was evaluated under laboratory and field conditions, and the results are documented along with the problems encountered and suggestions for improvement on future systems.

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CONTENTS

AN EVALUATION OF THE HARDENED
DIGITAL RECORDING SYSTEM

PART I. INTRODUCTION

1. Kaman Sciences Corporation (KSC) was contracted by the Defense
Nuclear Agency (DNA) Contract No. DNA 001-85-C-0279 to develop a self-contained
digital recording system (SDRS) for recording data produced by large-scale,
high-explosive (HE) tests. The result of this contract was to have been a
hardened, modular, five-channel data recording system. In FY 88, DNA tasked
the Waterways Experiment Station (WES), Instrumentation Services Division
(ISD), to evaluate the system's performance under laboratory and field test
conditions. This report is a statement of the assessment effort which has been
performed by WES to date.

2. The following is a list of the specifications and features of the
SDRS. Each specification is addressed later in the report.

> a. Each single channel recorder is constructed of
> aluminum with physical dimensions of 15.5 in. x 18.5 in.
> x 1.25 in. The cover for the battery compartment is 1.25
> in. x 2.75 in. Five of these units must fit in an
> aluminum cage with ribs welded on the outside for
> reinforcement. The physical dimensions of the cage are
> 20 in. x 13.25 in. x 24 in.

> b. The recorders are individually powered by 8-volt
> rechargeable battery packs constructed by connecting four
> 2-volt, 5AH lead-acid cells in series. Recorded data are
> protected in each recorder unit by separate lithium
> batteries (in the event the main batteries fail).

> c. The SDRS uses a hybrid analog-to-digital (A/D)
> converter with +/- 5V range and 12 bit digitization.

> d. Each recorder channel contains 64K x 16 words of
> memory which may be partitioned into 8 segments.

> e. The maximum sample rate of the digitizers is 2
> microseconds/point; each segment of memory can be
> programmed for different sample rates.

f. After the event, data are downloaded to 3.25 in. floppy disk via a battery powered Hewlett Packard Model 110 laptop computer and battery powered Hewlett Packard Model 9114 disk drive provided by KSC for the SDRS.

PART II. PRETEST EVALUATION OF THE SDRS SYSTEM

3. A significant amount of time was expended in determining how to operate the SDRS. The report provided by KSC was limited in its description of operating procedures and overall was inadequate. After receiving the SDRS at WES, the recorders were connected to the laptop PC computer. When the HPCOM command was executed, none of the five channels would communicate with the computer. We determined that the batteries were dead in all five SDRS recorders and in the communications box. Also, the communications parameters were set improperly in the computer. A call to KSC determined that the parameters should be set as follows:

> Baud Rate: 9600
>
> Data Bits: 8
>
> Stop bits: 1
>
> Parity: None
>
> Duplex: Half

Once these parameters were properly set and all batteries were charged or replaced, all recorders, except No. 2, communicated with the computer. The cover was removed from Recorder No. 2 and it appeared that this recorder had been destroyed in previous testing, since some electrical components were missing and others were broken. No further attempt was made to test it.

4. The signal conditioning was not the same in all recorders. Recorder No. 1 was configured for an external piezoresistive bridge and was set at a gain of 10. Recorder Nos. 3, 4, and 5 were configured with three arms of the bridge supplied internally, requiring only an external 350 ohm gage for completion (such as a strain gage). The instrumentation amplifiers in these recorders were configured for a gain of 1000.

5. The trigger requirements of each of the recorders were also found to vary. Recorder No. 1 requires a 5-volt pulse to trigger it. The other recorders require only 25mV to trigger, with the exception of Recorder No. 5, which often triggers immediately after it is armed. When Recorder No. 5 does not trigger immediately, it may be triggered by just touching the external BNC trigger input.

6. Data analysis also proved to an unacceptably time consuming procedure. Data are uploaded to an external 3.5 in. floppy disk drive and stored in a binary format. Lotus 123 is not capable of importing binary data, so the data must be converted to ASCII format before using Lotus 123. Also, Lotus 123, as configured on the laptop computer, is capable of loading only 2K data points. Therefore, an iterative procedure must be used to plot the appropriate 2K data points out of a maximum 64K data points. A software program, CONVERT.BAS, (written by personnel at WES) was required to be written in BASIC language to maximize the available memory and to convert the binary data into ASCII format.

7. Each of the remaining units was tested using the following procedure to determine the condition of the unit:

<u>a</u>. Establish communications by running the HPCOM program provided by KSC.

<u>b</u>. Initialize the SDRS channel using F4 "Unit Restart" function.

<u>c</u>. Modify signal conditioner to accept signal from front BNC connector and select gain resistors to achieve a gain of 10 in the signal conditioner.

<u>d</u>. Program digitizers for 2 microseconds sample rate in each segment. Disable autobalance function and calibration function, since these functions are not operating. Set the arm time and date to the present time and transmit the parameters. The communication line must be disconnected and reconnected in order to "clock" the recorder. Reload the parameters from the recorder to verify that the SDRS received the "ARM" signal.

<u>e</u>. Input a 1 KHz, 0.5 Vp triangle waveform into the signal BNC and monitor the signal at the A/D input. Balance the signal using the potentiometer on the signal conditioner board. The amplitude of the triangle (ramp) function should be +/- 5V. This ensures that the full range of A/D is tested. (Note: The signal conditioner is not powered until the recorder is armed.)

<u>f</u>. Disconnect the communication line. (Note: The communication power is not switched and should be disconnected at all times to avoid battery drain.)

g. Trigger the recorder by switching 5 V on the trigger input.

h. Connect the communication line and run HPCOM to reestablish communications with the recorder. Run the "F5, RELO*C PARAMS" function to verify that the recorder received the trigger. Go to the next menu and enter the desired filename and number of points to upload. Connect the external disk drive, and run the "F3, UPLOAD DATA" function.

i. Exit the HPCOM program and run the CONVERT.BAS program to convert the binary data to ASCII data. The maximum number of points which Lotus 123 can handle is 2,000 so an appropriate number of points to skip should be chosen.

j. Load Lotus 123 and import the converted data file. Run the graph routine and plot the data.

8. Since BASIC language is capable of accessing only 32K records in a file, the data must occur in the first 32K data points. Obviously, this is not acceptable for an operational system, since the other 32K of data are wasted. However, WES was not tasked for software development and KSC provided no software for this purpose. Tests were configured so that data arrived within the first 32K memory window and the CONVERT.BAS program provided an acceptable solution for system testing. Uploading data to the floppy disk drive took approximately 18 minutes per channel using the routine provided in HPCOM, causing considerable drain on the drive's batteries. Even with the AC charge cable plugged in, the batteries often ran down and the only alternative was to wait for the batteries to charge before any data uploading, converting, or analysis could occur. The electronic drive in the computer is insufficient for any realistic amount of data storage.

9. Communication with Recorder No. 4 was unreliable at first, then became impossible. It no longer responded to any attempt to communicate. The reason for this failure was not determined. Figures 1, 2, and 3 show the results of the procedure with a ramp function input to Recorder Nos. 1, 3, and 5. These recorders seemed to be working properly except for the intermittent trigger operation of Recorder No. 5. The cause of the 0.25V DC offset is undetermined. All A/D inputs were zeroed prior to testing. This offset may be

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a function of the A/D converter, or a software bug in either the data storage or data retrieval. However, this offset does not affect data quality.

10. An Endevco Model 2262, 25g piezoresistive accelerometer was connected to each recorder and the output signal was recorded. (Note: Only the accelerometer was hit to produce an acceleration record; the recorders themselves were not hit.) Excitation was provided to the accelerometer from the SDRS excitation 10 V output, which is enabled only when the unit is armed. Figure 4 shows the iterative procedure used to find the data and plot the points of interest from Recorder No. 2. Figure 4a illustrates data points 1 through 30,000, converting and plotting every 100th data point. This plot was used to determine a general location for the data. Figure 4b shows data points 19,000 through 21,000, converting and plotting all 2,000 points. Figure 4c is a plot of points 19,400 through 19,800, showing a better view of the initial acceleration. Figures 5 and 6 show the output of Recorder Nos. 3 and 5 with accelerometer inputs.

PART III. TESTING THE SDRS ON AN ACTUAL EVENT

11. The Misty Port I test in White Sands, New Mexico, provided a suitable opportunity for testing the SDRS. The test consisted of a 1,000 lb high explosive airblast detonation, at a burst height of 10 ft. Recorder Nos. 1 and 3 were installed in the cage and placed in a concrete vault approximately 60 ft from ground zero. Sandbags were used to couple the cage to the vault. The airblast overpressure level was approximately 60 psi, and the predicted acceleration level was 50 g's. The vault was covered with a steel plate, such that the SDRS was not exposed to direct airblast. Three Endevco model 2262, 200g accelerometers were mounted horizontally on the outside of the cage; two accelerometers were recorded using the SDRS, and one reference accelerometer was recorded in the Precision Test Bed (PTB) instrumentation bunker on a Pacific Instrument Model 9830 Transient Data Recorder.

12. Prior to installation of the recorders in the cage, each channel was set up to record a predicted acceleration of 200 g's (this included a sufficient safety factor). The following procedure was used to set up each recorder.

<u>a</u>. Remove the 14 screws around the perimeter and the 4 screws in the center of the unit. Remove the upper plate to allow access to the signal conditioning board.

<u>b</u>. Connect the signal leads of the accelerometer to the BNC SIGNAL INPUT and the excitation leads to the BNC EXCITE OUT connectors.

<u>c</u>. Use the following formula to determine the desired gain of the instrumentation amplifier:

$$G_d = 5V / (S_g * P)$$

where

G_d = desired gain,

5 = full scale A/D range, in volts

S_g = gage sensitivity, in V/g

P = predicted peak acceleration, in g's

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d. Use the following formula to determine the resistance values which achieve the desired gain for the instrumentation amplifier. See Appendix A for schematic diagram of the signal conditioning circuit to determine the location of R1 and R2.

$$G = R2/R1$$

where

G = amplifier gain

R1 = the input resistor to the instrumentation amplifier

R2 = the feedback resistor for the instrumentation amplifier

Solder these resistors on the signal conditioning board.

e. Verify that the gain of the signal conditioner is properly set by inserting a known signal V(i) into SIGNAL INPUT. Monitor the A/D input voltage V(o). Determine the actual gain G_a using the following formula:

$$G_a = V(o)/V(i)$$

f. Determine the sensitivity of the system at the A/D input as follows:

$$S_s = S_g * G_a$$

where

S_s = sensitivity of the system at the A/D input, in V/g

S_g = sensitivity of the gage, in V/g

G_a = actual gain of the instrumentation amplifier

g. Connect the accelerometer to the SDRS channel and monitor the output of the signal conditioner board. Adjust the balance pot on the signal conditioner board until the gage is balanced.

h. Replace the cover and tighten all screws.

14. Table 1 lists the setup of each accelerometer channel used in the Misty Port I test.

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15.   The SDRS cage, as provided by KSC, did not provide the required access for sensor cables, a trigger cable, a communication cable, or battery charge cable. Appropriate access holes were required to be drilled into the cage. The trigger, communication, and battery cables were attached parallel in the cage.

16.   Ground shock arrival time at the vault was predicted to be approximately 25 msec after charge detonation. Therefore, the SDRS recorder channels were programmed to sample at 2 microseconds/point in all eight segments. This provided 128 msec of total memory window (only 64 msec of BASIC accessible memory, which was sufficient).

17.   The SDRS channels have a feature which allows them to arm themselves at a preprogrammed time, but this feature proved erratic on Recorder No. 3, and was not functional on Recorder No. 1. Therefore, the SDRS channels were manually armed immediately prior to evacuation of the test bed, about 45 minutes prior to event deteonation.

18.   A +30 volt (peak), 1 microsecond width pulse from the firing unit was used to trigger the SDRS recorders.

19.   Access to the test bed was allowed about an hour after event detonation. Upon arrival at the site, it was determined that the communications line had been destroyed during the shot, so data retrieval was not possible until the vault was opened, which required an additional 30 minutes. The computer was reconnected to the SDRS and the status of each recorder was checked. Recorder No. 1 had not triggered, and the batteries were dead. The batteries had been fully charged prior to installation of the SDRS in the vault. Recorder No. 3 was triggered, and the data was uploaded to the floppy disk.

20.   A sample of the data recorded by Recorder No. 3 is shown in Figure 7. It appears that no actual data were recorded during the event. Figure 8 is a plot of the accelerometer which was recorded in the instrumentation bunker using "standard" digital data recorders. This plot shows a maximum acceleration at the SDRS of about 49 g's.

PART IV. POST-TEST EVALUATION

21. Recorder Nos. 1 and 3 were evaluated after return to the WES
laboratory to determine if the recorders had survived the shot. Each recorder
channel was triggered with a ramp function applied to its signal input. Figure
9 shows the output of Recorder No. 1. It appears that the A/D converter did
not survive the shot since the output is at -5V. Figure 10 shows the output
from Recorder No. 3. It appears that the A/D converter was also damaged in
this recorder, since the waveform has only 3-bit resolution (8 steps over its
full range).

PART V. ANALYSIS AND RECOMMENDATIONS

22. The physical dimensions of the PC board seem to approach "worst case" dimensions for destructive resonances. It is much more rational to configure the system on stacked, double-sided PC boards and use surface mount components to allow a more rugged, compact design capable of being housed in a smaller much more compact case. The housing could be designed to contain both the gage and the recording electronics, thus, achieving a totally self-contained recording system. Such a system would be highly portable, much less sensitive to shock, and more efficient in a variety of applications.

23. The size of the 8-volt battery pack could be reduced by at least a factor of two without affecting its charge capacity. Individual cells without casing could be wired together and potted to provide strength and compactness. There also are no lithium batteries on any of the prototypes, as indicated on the specifications. Some type of backup memory power is crucial to prevent data loss in the event of main battery failure.

24. The A/D converter seems to be the most damage-susceptible component in the SDRS. Hybrid A/D converters are highly susceptible to damage from shock. A custom monolithic A/D converter could withstand much higher shock levels, and a monolithic A/D converter with 12 bit resolution and acceptable speed should be on the market soon.

25. A memory of 64K words is only marginally adequate for data acquisition on this type of explosive testing. Higher memory would allow a greater flexibility in triggering and with state-of-the-art components, 128K words of memory would require no more physical space. The ability to partition the memory into 8 segments is a valuable memory-conserving feature.

26. A sample rate of 2 microseconds/point provides a system frequency response which meets most present analog and digital recording system capabilities.

27. The present signal conditioner contains an instrumentation amplifier with a gain-bandwidth product of 40 MHz. At a gain of 1,000, this provides only 40 KHz frequency response. The signal conditioner should be designed to provide 100 KHz frequency response at a gain of 1,000 to compete with existing systems.

28. Software programmable gain setting of the signal conditioner would eliminate the need to manually resolder board components, which proved to be a time-consuming operation due to the inaccessibility of the PC board. Programmable gain settings which vary with each memory segment would also be a valuable feature since these would allow for higher resolution of late-time data.

29. Since all transducer outputs are suject to drift over time due to heating (and other) effects on the sensor and cable system, an autobalance feature should also be included on future SDRS systems. In the present KSC-designed SDRS, balancing the gage requires removing the lid and turning a potentiometer while monitoring the A/D input. At the very least, the pot should be mounted so that it may be adjusted via a hole in the chassis, and external test points to the A/D inputs should be provided.

30. A method should also be designed to calibrate the gage/system using a shunt calibration resistor, or at least a built-in voltage insertion scheme. The calibration resistor should be located so that it could be changed with minimal unit disassembly. Since the calibration resistor would not be in the circuit during the event, it would not require a hardened mounting scheme.

31. Arming the system via the computer interface proves to be an unreliable procedure. Several attempts were often required before the SDRS received the arm parameters. The unit apparently did not always "cycle" properly when the communication line was unplugged. Also, the units did not reliably arm at a preprogrammed time of day. This would be a valuable battery conserving feature once it is proven reliable.

32. Trigger specifications were not given for the SDRS. Recorder No. 1 required greater than 5 V to trigger it, but had intermittent response to varying pulse widths. Recorder No. 3 seems the most reliable unit to trigger; however, the 25mV trigger threshold level makes it highly susceptible to inadvertent triggering due to noise. Also the pulse width required to reliably trigger the device is undetermined. The trigger threshold on Recorder No. 5 is unacceptable due to intermittent triggering immediately upon arming. A much more reliable triggering circuit is required since triggering is the most crucial aspect of any digital recording system. The ability to store pretrigger data in memory by cycling through the memory, beginning at arm

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time, would allow for a backup triggering scheme on the event, and would also allow triggering on an acceleration sensitive "switch" as a backup or primary trigger mechanism.

PART VI. CONCLUSIONS

33. The SDRS, in its present design configuration, is not yet ready for evaluation on actual test events. Many critical design problems are unresolved. The following problems were encountered while attempting the evaluate the system:

    <u>a</u>. Multiple attempts were required before communication could be established with the recorders.

    <u>b</u>. The SDRS battery power supplies and computer battery power supplies will not retain sufficient charge for required operations. Work was required to be periodically stopped until batteries were recharged.

    <u>c</u>. The trigger mechanism is unreliable; the trigger circuit must be better designed and fully documented.

    <u>d</u>. No provision is made for calibration of the sensor; the intentions of the preload calibration segment are undefined.

    <u>e</u>. Balancing a sensor is cumbersome in the laboratory, and impossible under field conditions, due to the time required to disassemble the recorder to access the signal conditioning board.

    <u>f</u>. Software for data conversion was not provided and data analysis was not possible until the CONVERT.BAS program was written. Provisions should be made so that both the SDRS and the data storage device (disk drive) easily interface with a computer of more memory capacity and faster operating speed. This would allow the use of more efficient data analysis programs.

34. The SDRS in its present form is an inadequate and unacceptable attempt to solve the hardened, self-contained data acquisition system requirement. The KSC prototype merely demonstrates that the electronic components exist which allow for a battery-powered, high performance recording system. Commercial products currently available from Pacific Instruments, DSP, and other companies have the performance and features demonstrating the feasibility of such a system hardened to between 50 and 100 g's.

35. WES presently has a super-hardened, miniature, self-contained, digital recording system which is highly portable and capable of recording high

resolution data. The device is available in configurations capable of withstanding upwards of 100,000 g shock loadings. The WES device is a single card using state-of-the-art, double-sided, surface-mount technology with a variable sample frequency (up to 1 MHz) and 128K sample memory (on-board) expandable to 512K samples by single chip replacement.

Table 1 : Setup Parameters for the Accelerometers on the Misty Port 1 Test Event.

AH-1 and AH-2 were recorded on the SDRS recorder channels no. 1 and no. 2.

AH-7 was recorded in the PTB instrumentation bunker. All gages were 200 g range

MEASUREMENT NUMBER	RECORDER LOCATION	SERIAL NUMBER	GAGE SENSITIVITY	PREDICTED PEAK	DESIRED GAIN	INPUT RESISTOR	FEEDBACK RESISTOR	ACTUAL GAIN	SYSTEM SENSITIVITY
1	SDRS	KE-60	.00234 V/g	200g	10.6	10 kohm	1 kohm	10.95	.024 V/g
2	SDRS	PA-59	.00135 V/g	200g	18.5	20 kohm	1 kohm	20.24	.027 V/g
3	PTB	US-76	.03225 V/g	200g	4.4	N/A	N/A	5	.011 V/g

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KSC #1 RAMP FUNCTION OUTPUT
(Input was a 1kHz, .5 Vp Ramp Function)
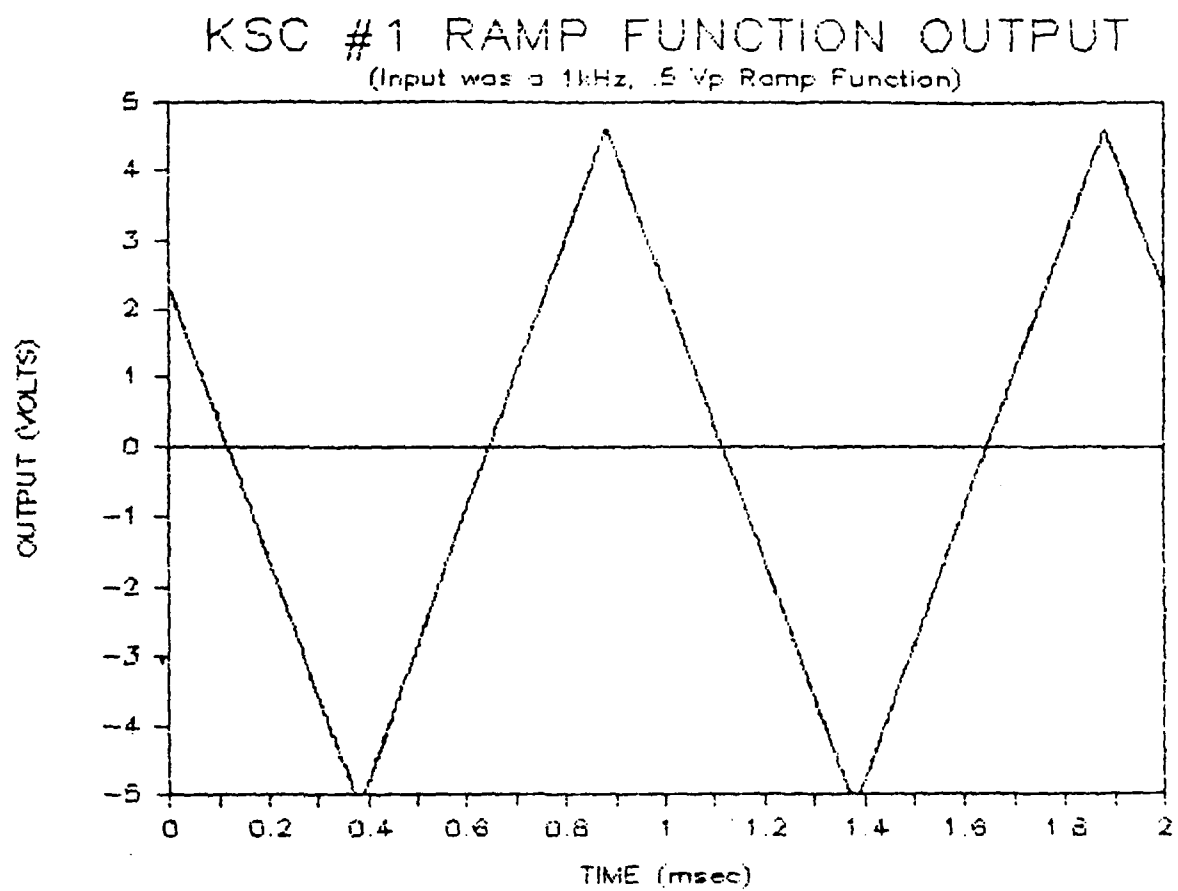
Figure 1.   Recorder No. 1 with Ramp Input.

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KSC #3 RAMP FUNCTION OUTPUT

(Input was a 1kHz, 5 Vp Ramp Function)
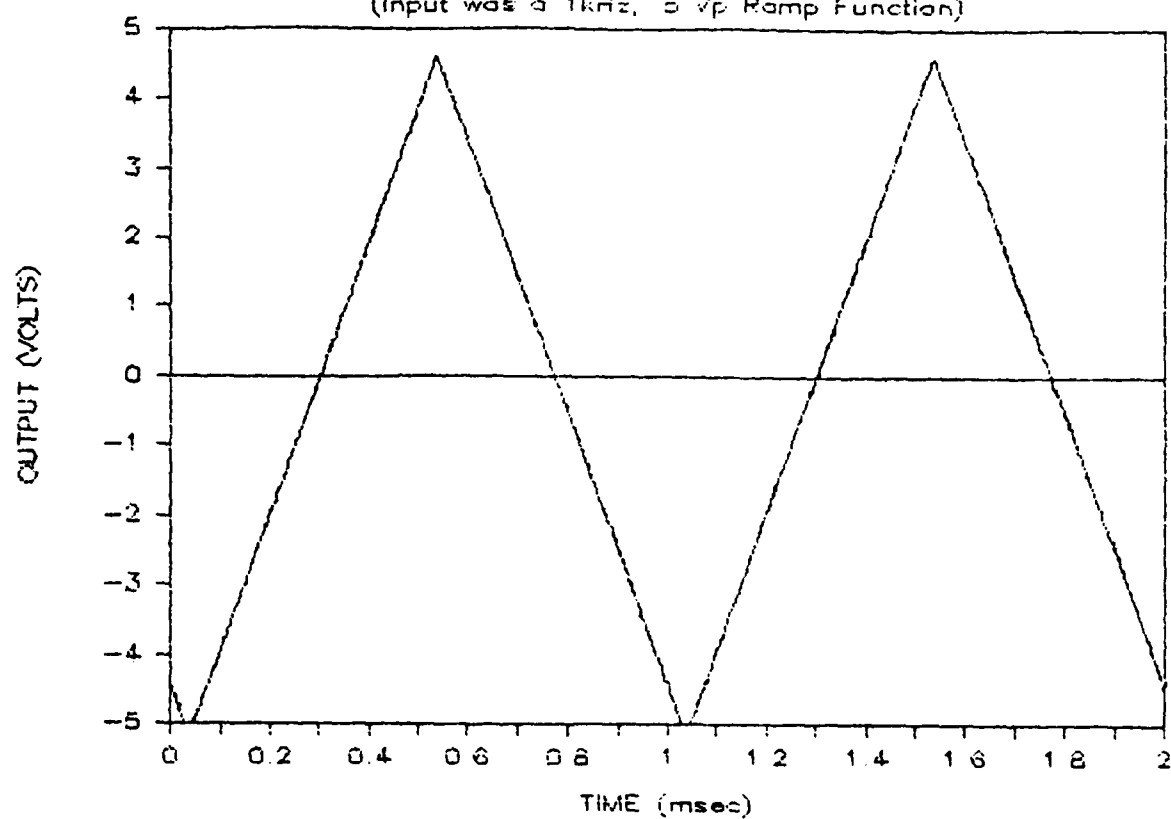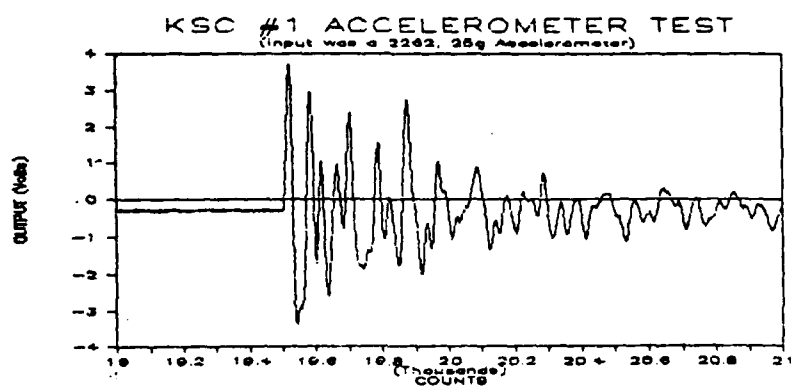

Figure 2.   Recorder No. 3 with Ramp Input.
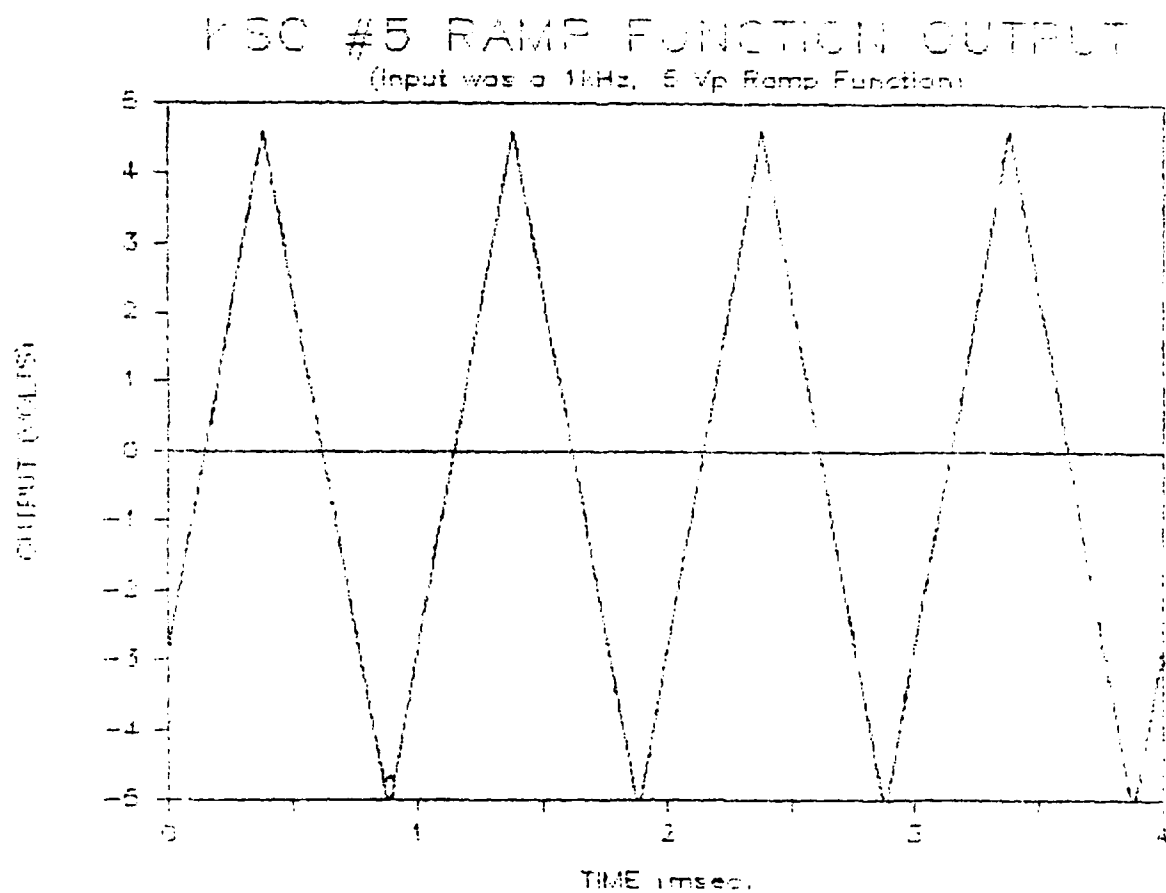
Figure 3.   Recorder No. 5 with Ramp Input.

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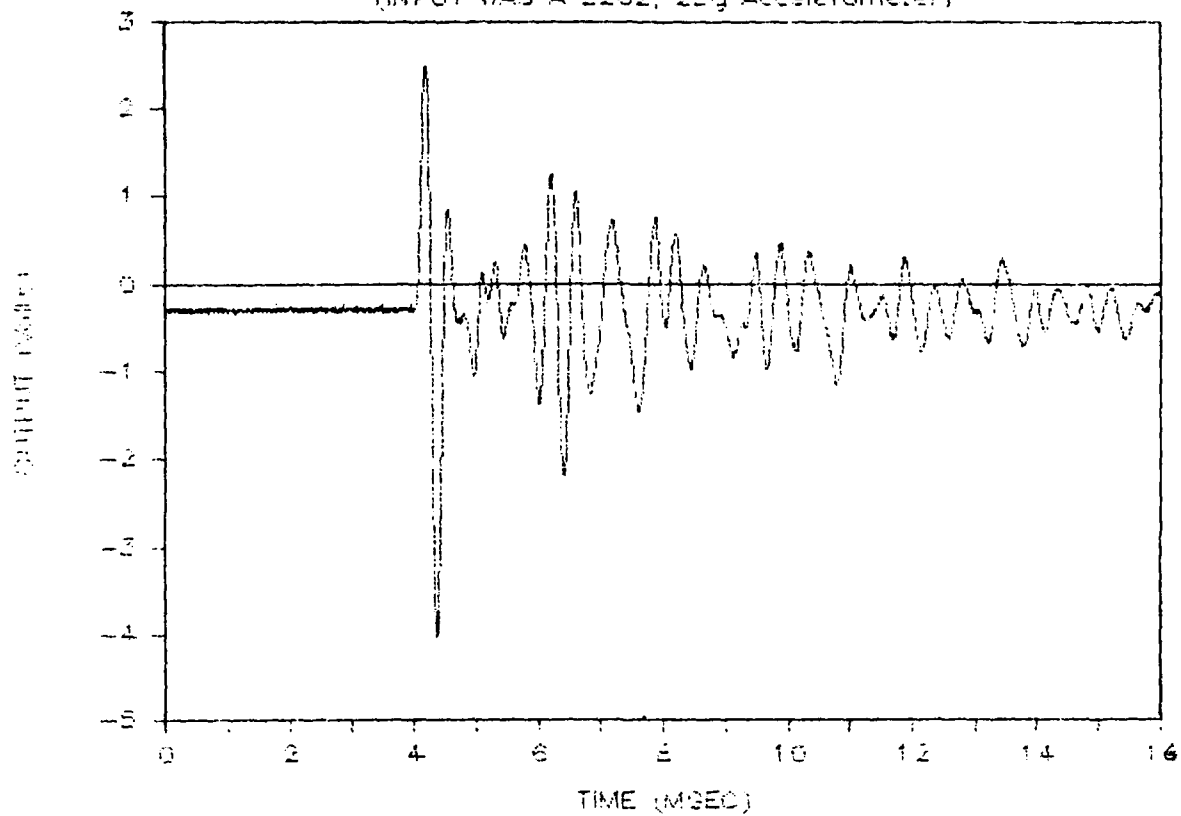**KSC #1 ACCELEROMETER TEST**
(Input was a 2262, 25g ACCELEROMETER)

(a)

KSC #1 ACCELEROMETER TEST
(Input was a 2262, 25g Accelerometer)

(b)

KSC #1 ACCELEROMETER TEST
(Input was a 2262, 25g Accelerometer)
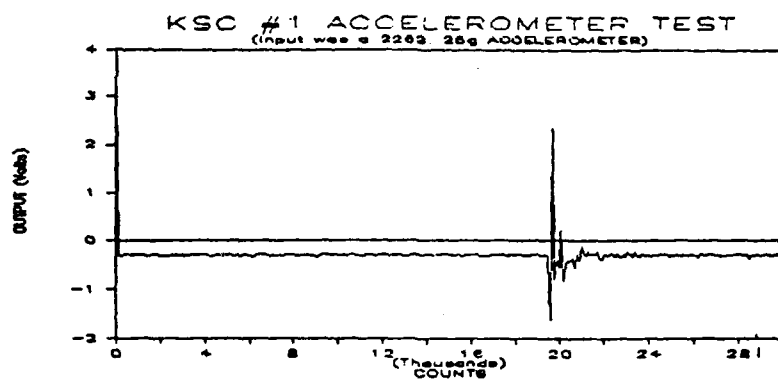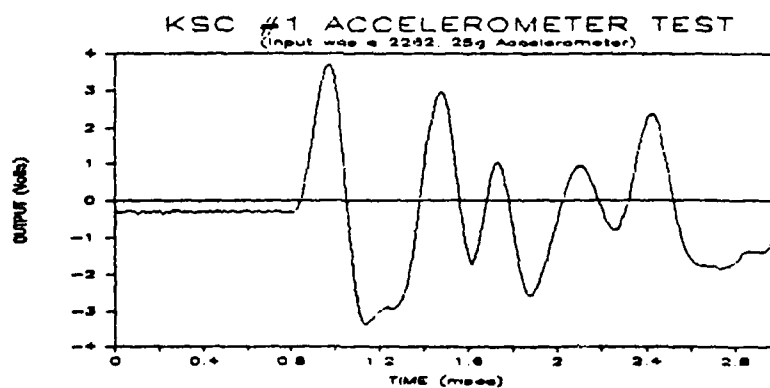
(c)

Figure 4.   Recorder No. 1 with Accelerometer Input.

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Figure 5.   Recorder No. 3 with Accelerometer Input.

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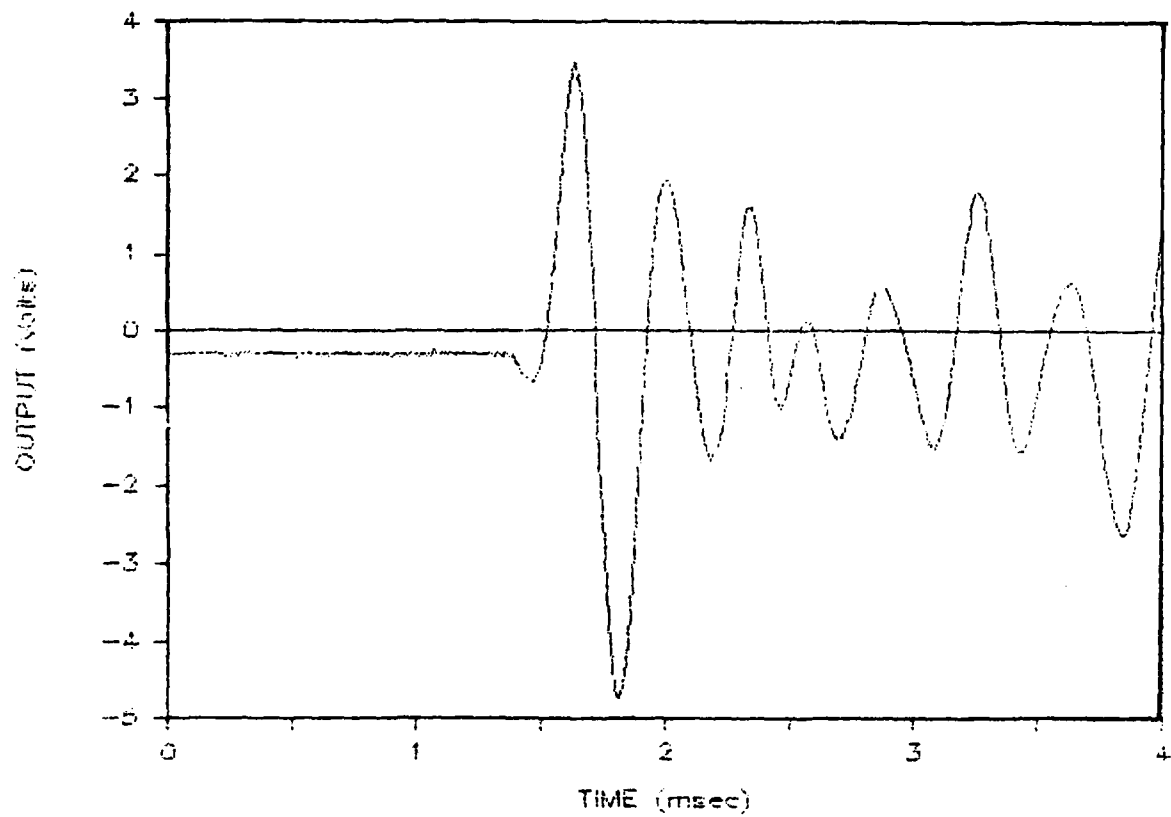
Figure 6.   Recorder No. 5 with Accelerometer Input.

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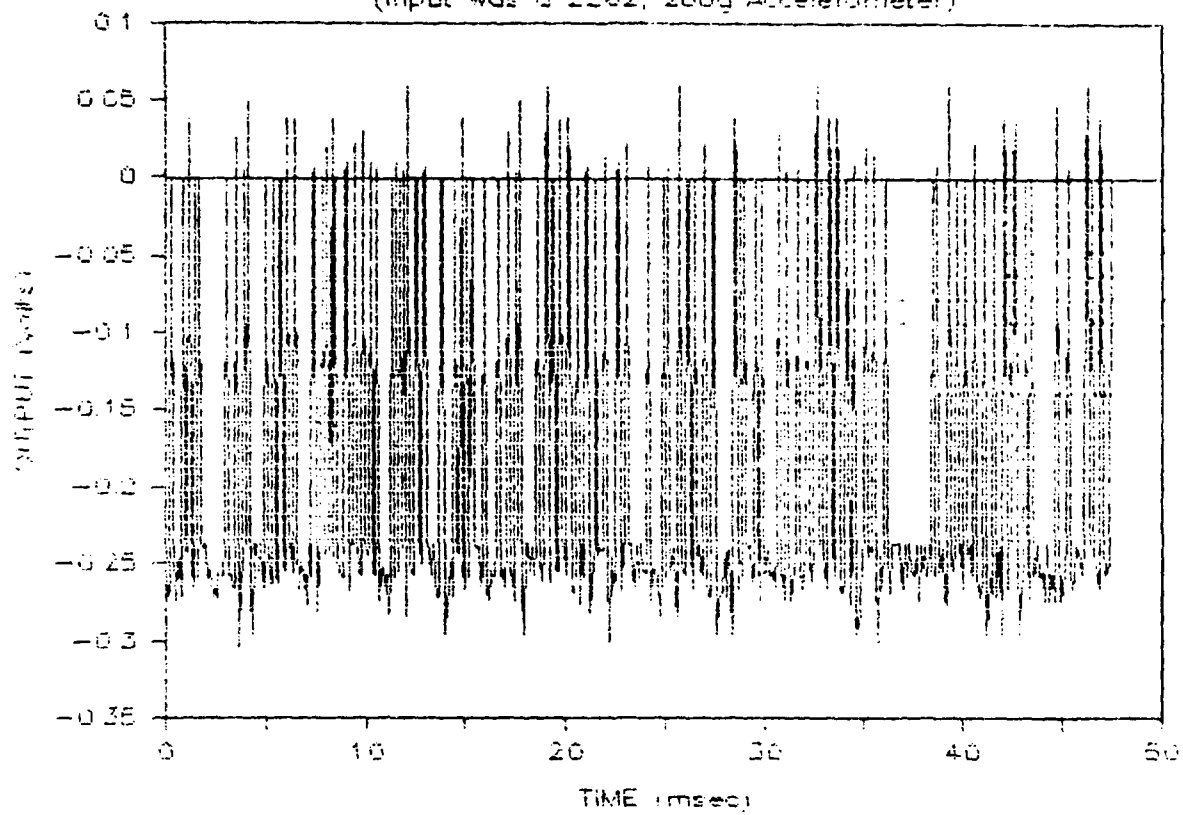
Figure 7. Plot of Memory Contents of Recorder No. 3 After Misty Port 1 Event.

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Digital Gage
Array Size. 60050
Cal val   109.322
Deflection   -1635

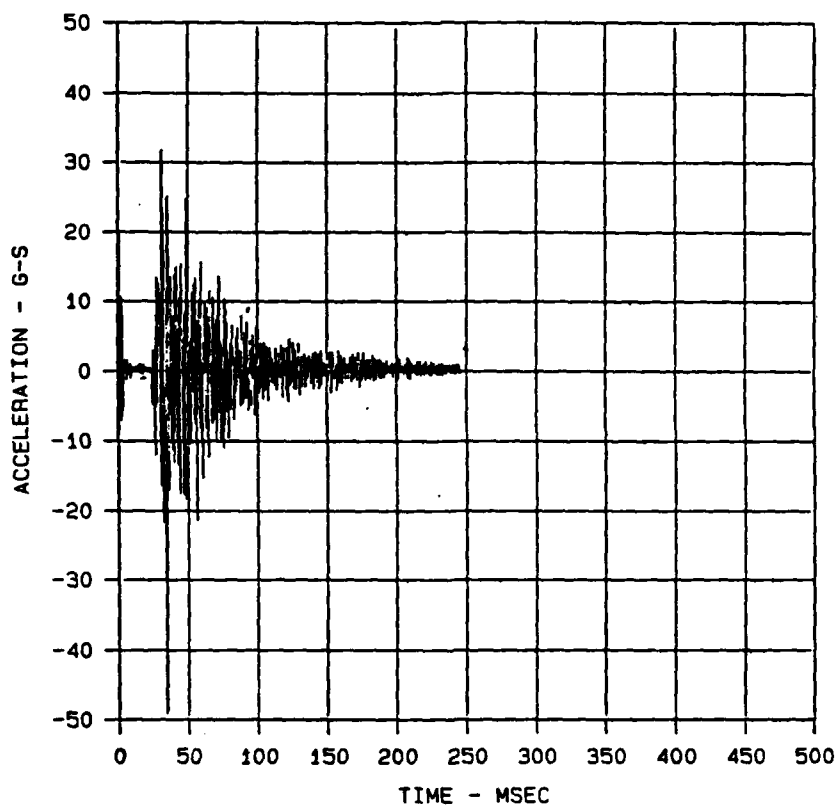MISTY-PORT-1   AVSR1

TOR 55

250   KHZ   7-SEP-88

Figure 8.   Reference Accelerometer as Recorded
            on Pacific Model 9830 Transient
            Data Recorder in Instrumentation Bunker.

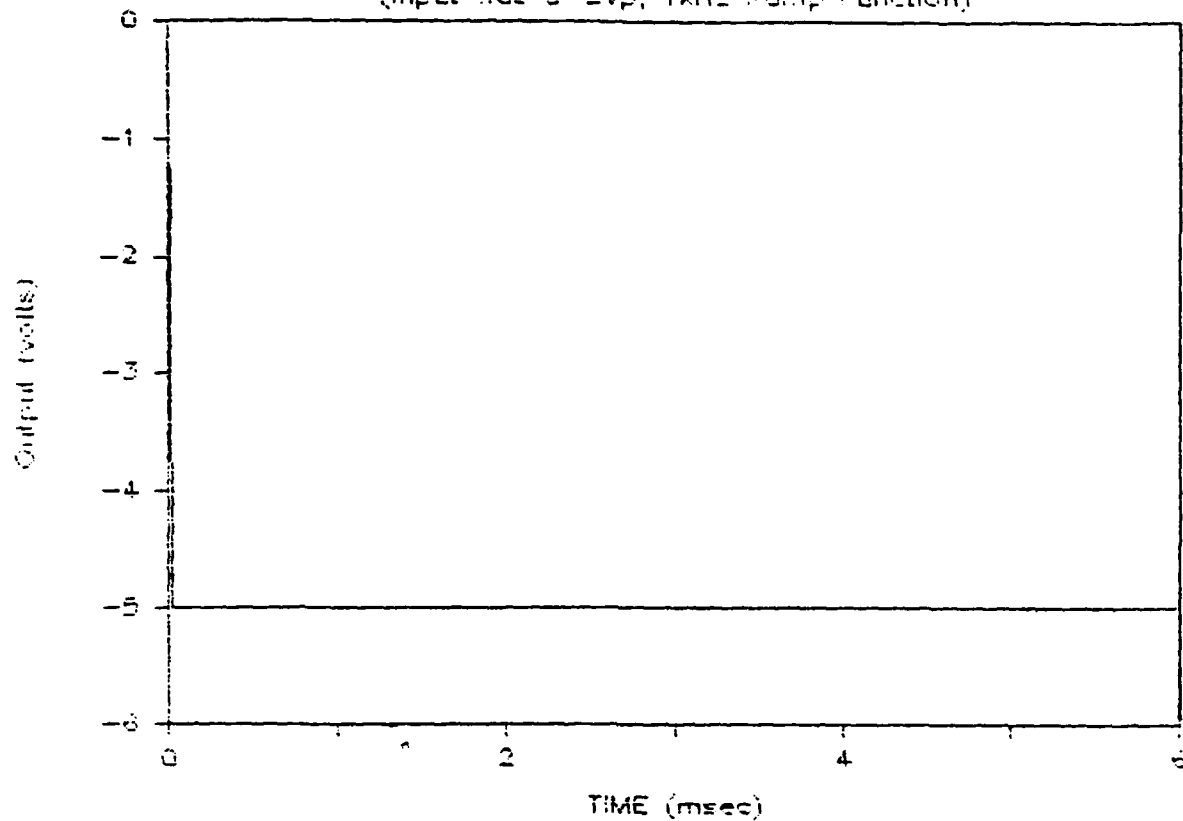KSC #1 Post-Shot Operations Test
(Input was a 5Vp, 1kHz Ramp Function)

Figure 9.   Post-Test Display of Recorder No.1   Data.
Input was a 0.5Vp, 1 KHz Ramp Function.

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KSC #3 POST-SHOT OPERATIONS TEST
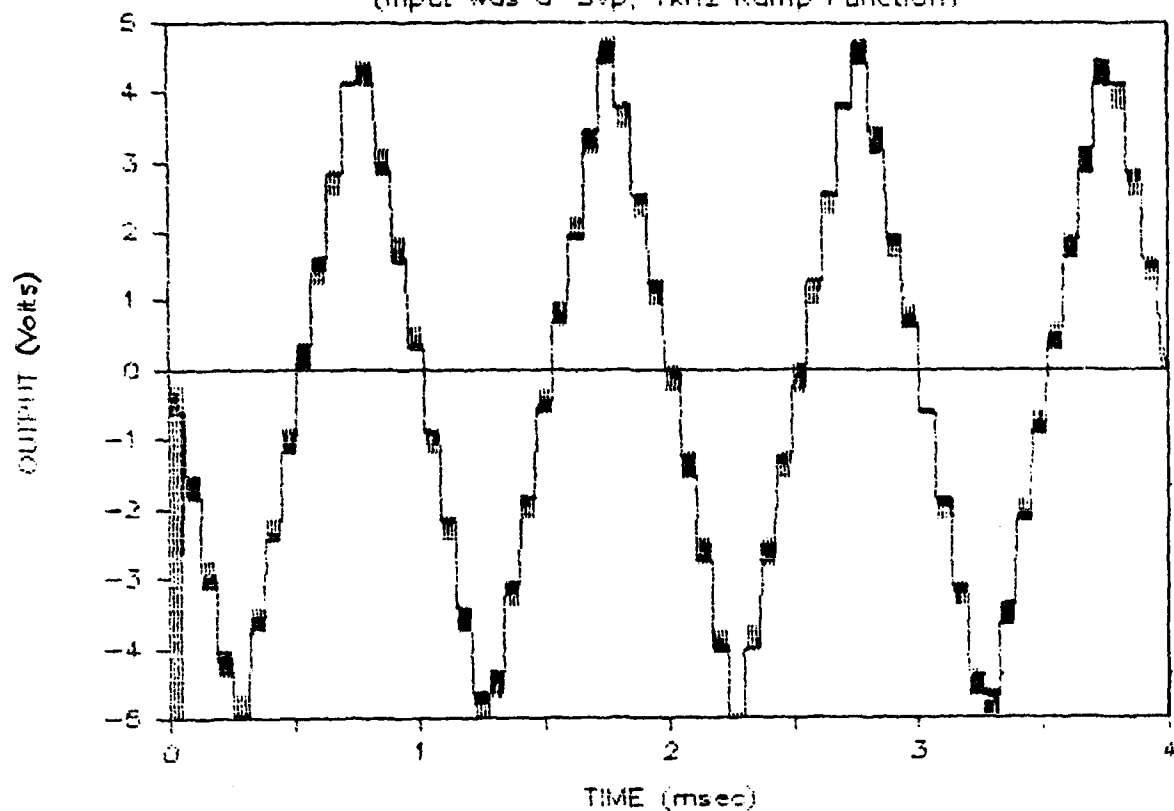(Input was a 5Vp, 1kHz Ramp Function)

Figure 10. Post-Test Display of Recorder No. 3 Data.
Input was a 0.5Vp, 1KHz Ramp Function.

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APPENDIX A.   SCHEMATIC

Schematic of modified KSC SDRS signal conditioning board showing location
of R1 and R2 for gain adjustment.